

Integrating Safety and Environmental Sustainability for Research Laboratories

John A. Howarter
Environmental & Ecological Engineering
Purdue University

howarter@purdue.edu

Pollution Partners Annual Meeting
September 28, 2016

- Collaborators:
 - Purdue Radiological & Environmental Management
 - EEE graduating class of 2015
 - Prof. Larry Nies
- About John Howarter
 - Prof. in Environmental/Materials
 - 3 yrs chair of Lab Safety committee
 - Directly responsible for 1500 square ft wet lab
 - Teach Senior Design; Industrial Ecology & LCA

Lab Safety in Academia

- The bottom line in lab safety is knowing what the hazards might be and how to avoid them
- Lab Safety always comes back to paying attention to proper procedure
- **“We have to change the paradigm where faculty and students say they never have had an accident.”**
- Schools have a 10 to 50 times greater frequency of accidents than does the chemical industry, though they tend to be smaller.(Source James Kauffman, Lab Safety Institute)

- A huge difference exists, he says, between university and industry labs. “There are industrial labs where the first time you are caught not wearing appropriate eye protection, you’re fired. That would never happen in an academic lab. It is a difference in culture.”
- DuPont has a policy that if you get caught in lab without eye protection, you get warned the first time, sent home for the day the second time, and fired the third time.
- Source: <http://pubs.acs.org/cen/government/88/8805gov1.html>

Sustainability must integrate human health and safety as paramount.
There is no point in asking how to be more sustainable if safety is in question.

Causes of Lab Accidents

- Lack of working understanding of hazards
- Improper or unintended use of equipment
- Inexperienced
- Distractions, lack/loss of attention to task
- Broken, damaged glassware or equipment
- Other

If users do not understand hazards, any sort of risk assessment of lab activity has failed. Academic labs continuously are dealing with this issue.

Typical Chemical Safety Rules

- Prior to Working with Chemicals
 - Obtain and Read the MSDS before working with chemicals
 - Obtain approval for working with special chemicals (HF, HClO₄, cyanide, arsenic)
- While Working with Chemicals
 - Wear appropriate PPE
 - Wear appropriate clothing – no shorts or sandals
 - Work in fume hood if possible
 - Label all containers
 - Do not work alone in the laboratory
 - Do not eat or drink in the laboratory
- When Finished
 - Properly label and store chemicals
 - Clean up all spills
 - Properly dispose of waste

Typical Safety Training: Chemical Responsibility

- Ordering Chemicals
 - Purchase order must be signed before turning in to business office.
 - MSDS needed for new chemicals.
 - Purchase only what you need.
 - Scale down processes as much as possible.
 - Determine storage needs before ordering.

Typical Safety Training: General Safety Guidelines for Hazardous Waste Management

1. Determine if your waste is hazardous
2. Identify and separate waste by class
3. Label hazardous waste containers
4. Complete Hazardous Material Pickup Request
Form

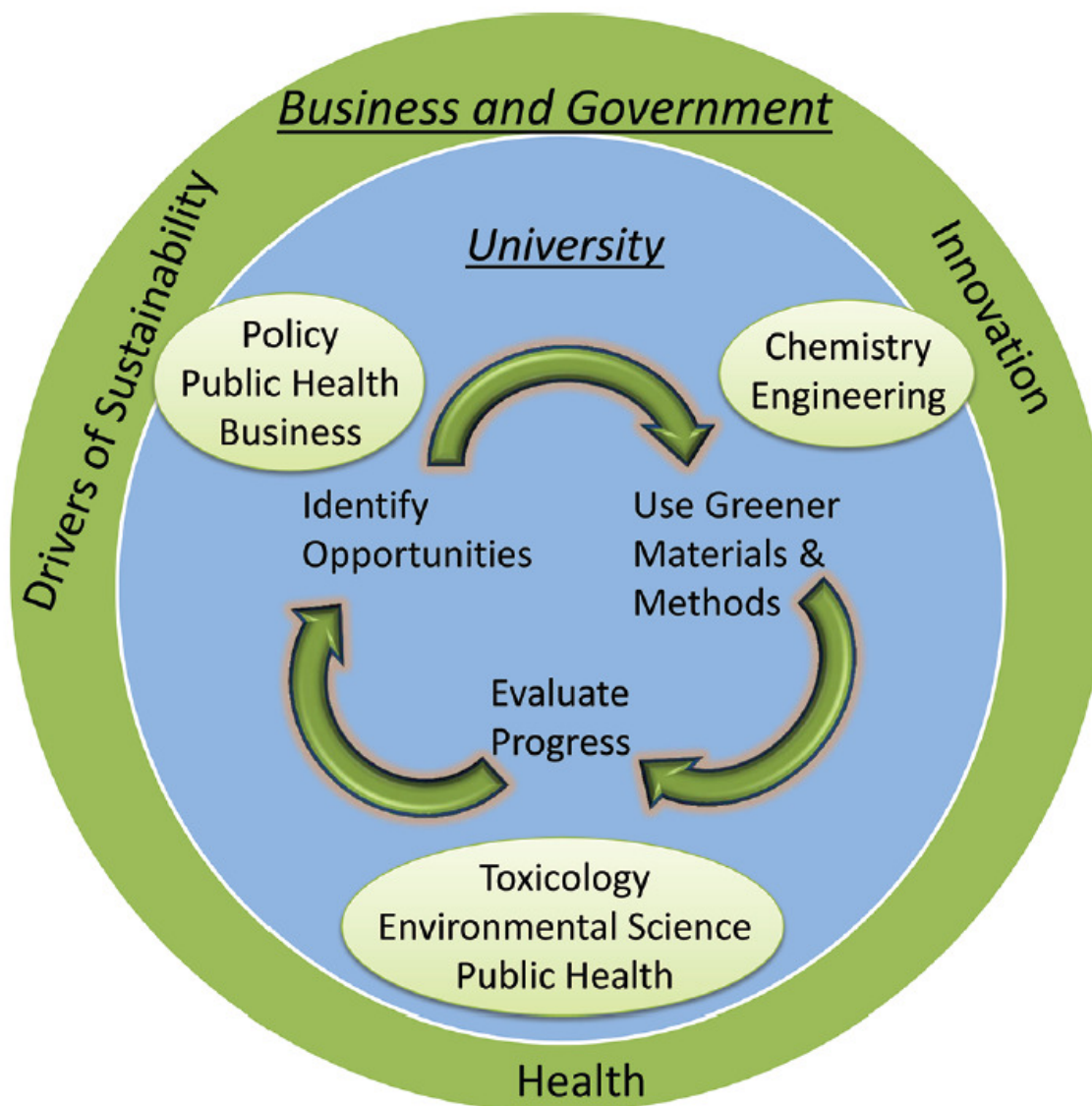
WASTE 'decisions' are centralized and designed for user simplicity. The user is almost always "off the hook" for environmentally responsible design and decision making.

Result of hydrofluoric acid vapor; examples of
poor chemical housekeeping
Bad for human health, bad for environment



Collaboration Across Disciplines for Sustainability: Green Chemistry as an Emerging Multistakeholder Community

Alastair Iles^{*,†} and Martin J. Mulvihill[‡]



How to Engage University Students

- Survey of Intro Chemistry Students at UC-Berkeley, 2012

	Strongly agree	Somewhat agree	Somewhat disagree	Strongly disagree
I believe Green Chemistry techniques and practices are important to modern society.	64.5% (749)	30.1% (350)	3.3% (38)	2.2% (25)
I believe Green Chemistry is applicable to my chosen field or discipline.	24.0% (278)	44.5% (516)	26.3% (305)	5.3% (61)

Approaches where Green Chemistry plays a role

1. At the most basic level: *Pollution Prevention* (P2)

- Improved operational practices
(lowering energy consumption, improving yields)
- Batch vs. continuous processing?
(batch processes may increase yield but continuous process may save energy)

2. Development of *greener processes* to manufacture unchanged chemical products: (Green Chemistry Level 1)

- *Example:* Avoid chlorine compounds if chlorine is not in the final product

3. Formulation of *alternative chemicals* for the same application: (Green Chemistry Level 2)

- *Example:* CFC substitutes

4. *Avoidance* of chemicals: (Green Chemistry Level 3)

- Switch from herbicides and pesticides to genetic engineering (trade offs?)
- Switch to organic farming (enough land?)
- Switch from traditional to digital photography (other industries, too?)
- Use colored plastics instead of painted metals (or simply avoid color)
- Switch from petroleum fuels to biofuels or hydrogen.

Definition, Goals and Methods of Green Chemistry

Green Chemistry, also called **Benign Chemistry** or **Clean Chemistry**, refers to the field of chemistry dealing with:

- synthesis (the path to making chemicals)
- processing (the actual making of chemicals)
- use

of chemicals that reduce risks to humans and impact on the environment.

Shift away from the conventional approach of end-of-pipe treatment to pro-active action by means of

- pollution prevention
- design of clean processes
- design of benign chemicals.

Eco-Efficiency

- **Cleaner Processes**
(Pollution Prevention)
 - *Reduced Emissions, Manufacturing and paint methods*
 - Assumes product function and concept are fixed
 - Usually involves incremental refinement of production/manufacturing processes to reduce waste and its byproducts

Cleaner Products *(Environmental Responsibility)*

- *Use of recycled products and environment friendly materials*
 - Fundamental product designs are still dynamic
 - Takes into account all stages of the product life cycle, from material selection to end-of-life use and recovery
- **Sustainable Resource Use**
(Industrial Ecology)
 - Evaluate product and production system as a whole
 - Includes supplier and customer impacts on resource consumption

Key Principles of DfE

EPA's role in DfE

The EPA responded to these Eco-Efficient approaches in the early 1990s, manufacturers started thinking in terms of "design for" qualities in their products and processes. The EPA recognized the need for competitive but environmentally preferable technologies. As a result the EPA's Design for the Environment (DfE) Program was developed.

<http://www.epa.gov/dfe>

EPA's role in DfE

The EPA:

- **Assists companies to integrate health and environment considerations into business decisions. This is aimed at prevention before pollution is created.**
- **Examines the hazards of chemicals used in an industry and pollution prevention.**
- **Assesses alternative processes, formulations, and emerging technologies.**
- **Promotes risk reduction through cleaner technologies and safer chemical choices.**

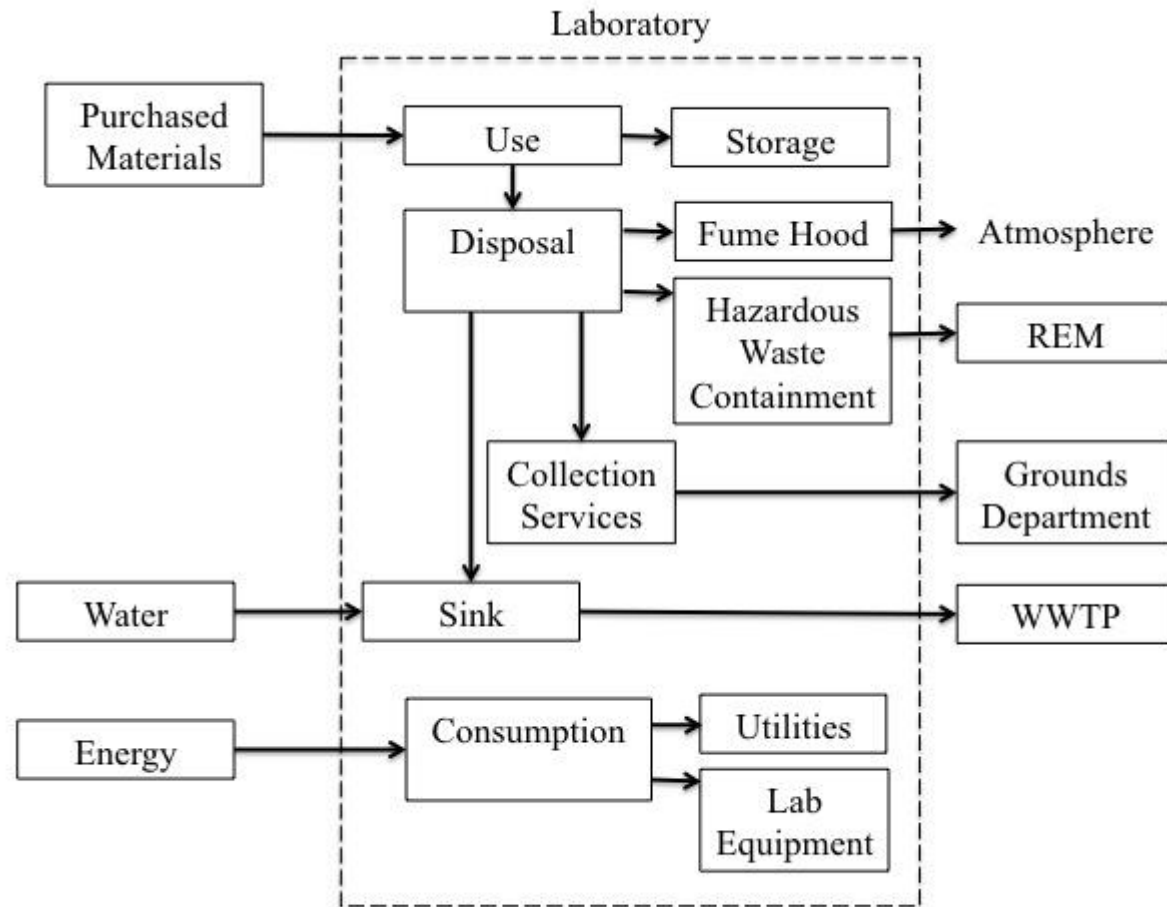
Incentives for Safe Academic Labs

- Challenge of incentives.
 - Every research lab is unique
 - High cost/high payoff attitude
 - “no time” for substitutions of ‘inferior’ chemicals
 - To incentivize safety, costs are largely born centrally (no direct cost to PI for waste management)
 - Additional challenge of low volume work, frequently changing lab activities

Collaboration with REM

- Purdue – REM sponsored two senior design projects with the open ended goal of pursuing more sustainable lab practices
 - Team 1: holistic ‘sustainable lab’
 - Think LEED – Gold type certification
 - Team 2: Value recovery from high purity waste

Where are the process hotspots?



Client Concerns

- Unlabeled, expired chemical waste
- Compliance with EPA
- Excessive chemical waste generated from labs
- Phantom energy losses (fume hood!)
- Waste lost down the drain / up the vent

Solution

- Incentive-based competition to reduce overall lab waste
- Green Lab Certifications
- Goals and Objectives
 - Lower all waste (chemical/solid/energy)
 - Stimulate the sustainability atmosphere in Purdue labs
 - Open the door for more sustainability efforts
- Structure:
 - Point system based on lab activities
 - Incentives for “top-performing” labs



Existing Programs

- Sustainability
 - Environmental
 - Economic
 - Social
- Input Reduction efforts
 - Purchasing guides – MIT's Green Chemicals Alternatives Purchasing Wizard
 - Programs to keep fume hood closed
 - Programs to defrost freezers
- Output Reduction efforts
 - Training/ awareness
 - Setting lab goals
 - Maintain a chemical inventory list

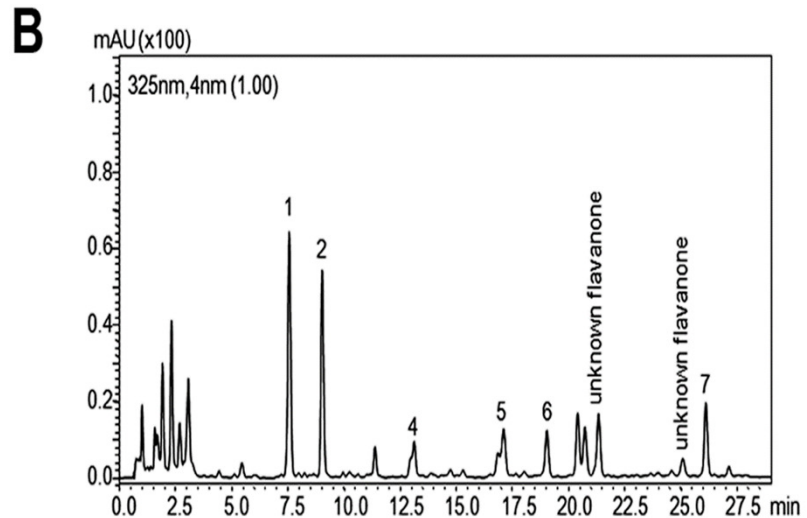
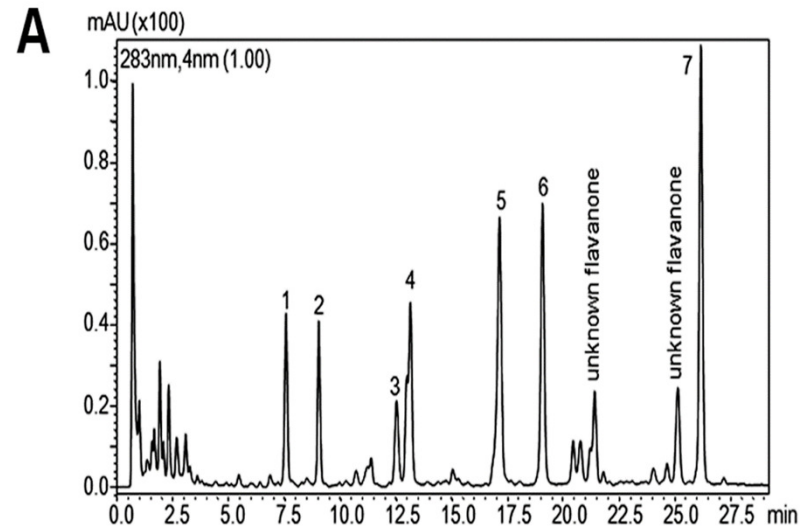


University	Program Instigator/ Regulator	Program Details	Proposed Benefits/ Incentives
Harvard University	Faculty of Arts and Sciences Green Program with partners from the Office for Sustainability	<u>Green Certification</u> <ul style="list-style-type: none"> • Meet with a representative • Rep tours the lab and gives a list of recommendations • Lab group chooses 3 goals from the list • Reps work with the lab to achieve them 	<ul style="list-style-type: none"> • Specific feedback on sustainability questions • Free resource program access • Improved awareness about sustainability for lab members • Sense of community with lab members and other certified labs

Arizona State University	Department of Environmental Health and Safety with partners from Office of University Sustainability Practices	<u>Green Certification</u> <ul style="list-style-type: none"> • Self assessment • Complete 3 goals from checklist • Annually add 2 goals 	<ul style="list-style-type: none"> • Claim green certification on grant applications • Personalized follow up from program coordinators • Recognition on ASU website
Washington University	Environmental Stewardship & Sustainability Office - Green Laboratory Committee	<u>Competition & Green Certification</u> <ul style="list-style-type: none"> • Application/Committee review of green lab certification • Moves to a different school/college every year • Easy to implement 	<ul style="list-style-type: none"> • Green Lab certification • Lab-specific prizes: bike gear, mechanically powered flashlights, etc. • Encourage communication and positive neighbor relations

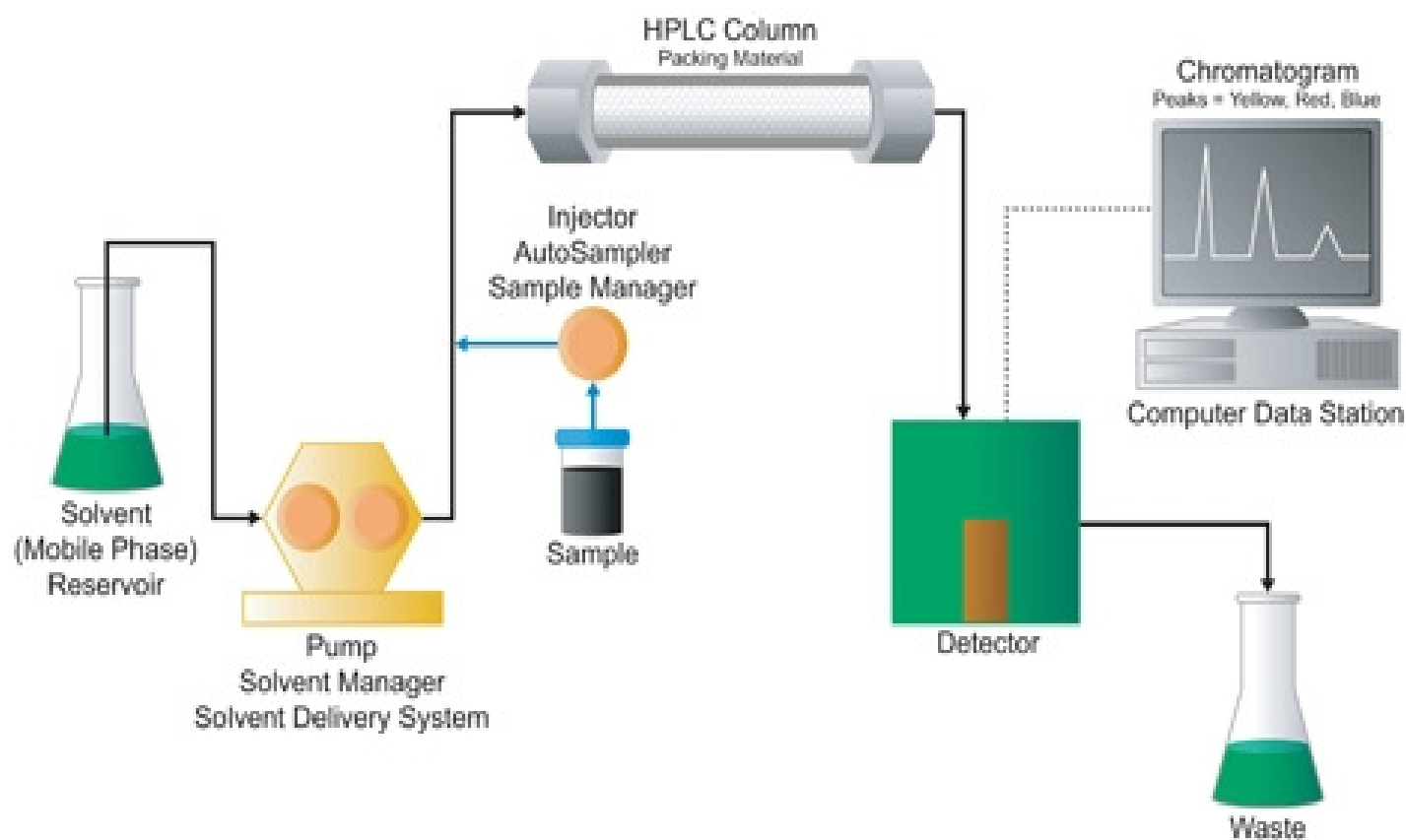
HPLC Case Study

- High Performance Liquid Chromatography (HPLC)
 - Used to analyze chemical composition of a sample
 - Uses solvents to carry sample
- Purdue HPLC machines produce roughly **13,200** gallons of solvent waste per year
- \$190-\$378 per gallon to buy new solvent



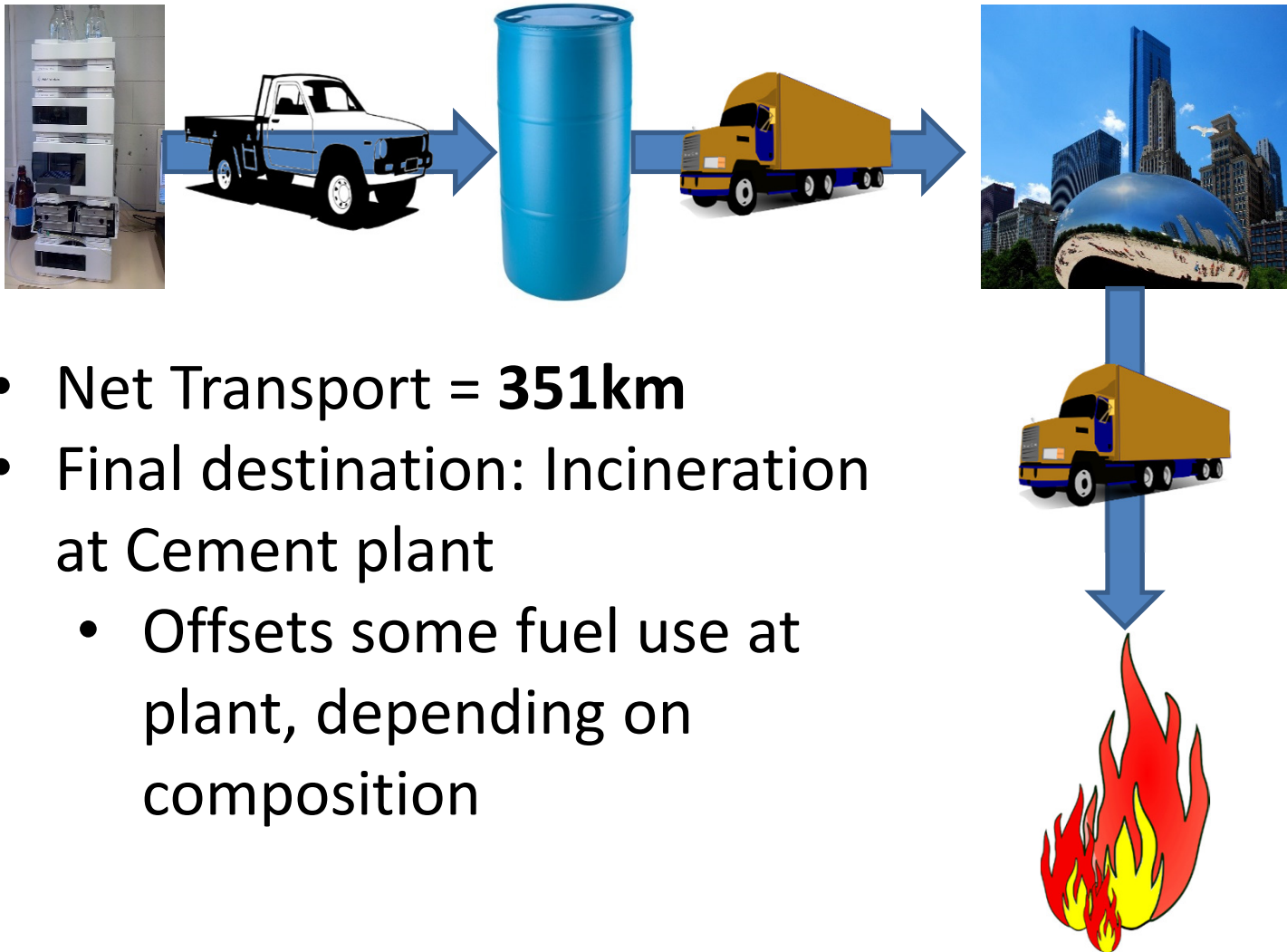
Refere
nce

Standard HPLC system



<http://www.pharmacelsus.de/hplc/>

Current Management Strategy



Design Criteria

Environment, Society, and Economy

- Reduction in solvent use
- Energy used per volume of waste treated
- Ease of use
- Safety
- Technical simplicity (robust design)
- Initial
- Operating costs

Fate of HPLC Waste

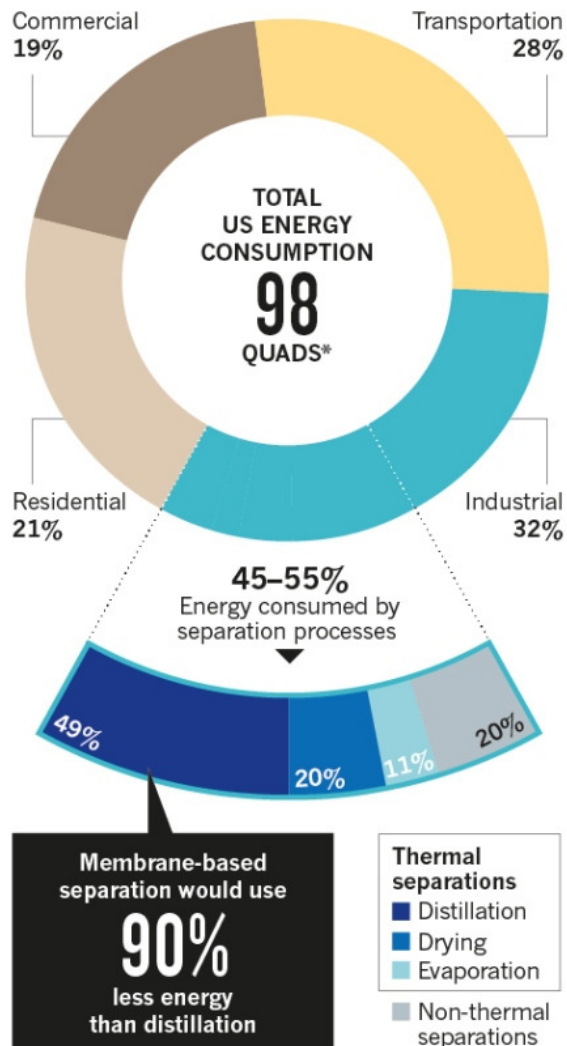
Process	How it Helps	Main Drawback(s)
Reuse as cleaning agent	Reduce the cost of lab cleaning agents	Methanol needs to be extracted from HPLC waste stream
MTG (Methanol to Gasoline)	Convert methanol into gasoline	Not enough methanol to sustain MTG cycle
Lyophilisation (freeze-drying)	Reduce waste volume by removing water	Too energy intensive to be cost effective
Activated charcoal bed filtration	Remove contaminants from solvent mixture so the solvents can be reused.	End purity of solvent mixture too low
charcoal filtration + distillation	Remove contaminants from solvent mixture so the solvents can be reused.	End purity of solvent mixture too low
Neutralization for drainage	Reduce the cost of disposing of the waste.	Not possible for the chemicals considered.
Membrane Separation	Separate methanol and acetone nitrate by filtering solution.	1. Purity of output is not acceptable. 2. Need higher selectivities than relative volatilities in distillation.

Conclusions

- Solvent Recovery System (most feasible)
 - Reduces overall solvent use → lab operational costs reduced
 - Proven technology, commercially available
 - Retrofit existing HPLC machines
- Dewatering by Distillation
 - Does not reduce solvent use
 - Only saves a small amount of money for waste treatment
 - Potentially high energy costs for distillation
- Supercritical CO₂
 - Technically very difficult
 - High operating costs
 - Recover most solvent
- #4 is there a better value recovery option as a 'co-product'?

CUTTING COSTS

Chemical separations account for about half of US industrial energy use and 10–15% of the nation's total energy consumption. Developing alternatives that don't use heat could make 80% of these separations 10 times more energy efficient.



*A quad is a unit of energy equal to 10^{15} British Thermal Units (1 BTU is about 0.0003 kilowatt-hours).

©nature

- Purification and separations are highly energy intensive.
- How can we best recover the value of slightly contaminated wastes

A FRAMEWORK FOR HABITUAL ORGANIZATIONAL EXCELLENCE

Culture is behavior over time

Teamwork is an effective mechanism to structure and practice the desired behaviors

Continuous learning and improvement allows us to embed team behaviors in the clinical work we care about

EVOLUTION OF A CULTURE OF SAFETY AND RELIABILITY

